Flexible configuration of wireless sensor network for monitoring of rainfall-induced landslide

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ABSTRACT: Establishment of wireless sensor network for Monitoring and Early Warning System (MEWS) of rainfall-induced landslide is still a challenging task due to problems of energy consumption. This research aim is to propose a new flexible system for the configuration of MEWS for rainfall-induced landslides. The proposed system is an integration a star topology and a tree topology, in which, the star topology is automatically used for the sensor nodes around the gateway node, whereas the tree topology is adopted for the other nodes. Consequently, the proposed configuration method is flexible and capable to save the energy consumption in the MEWS. Experiment result showed that the performance of the MEWS with the proposed method Wireless Sensor Network is better than those from the systems only use the tree topology or the star topology. The result of this study is useful for designing WSN for MEWS of rainfall-induced landslides.

KEY WORDS: *Landslides, Wireless Sensor Network, Early Warning, Topology, Vietnam.*

1. INTRODUCTION

Monitoring and Early Warning System (MEWS) for rainfall-induced landslide is an efficient tool for landslide management and its risk reduction. However, design and implementation of landslide MEWS are not easy tasks because they are dependent on various factors. One of these factors is the telecommunication system that uses to send timely the monitoring parameters of the landslide to the station for further analyzing and making decision.

An effective telecommunication system could be derived with the use of a relatively new technology of Wireless Sensor Network (WSN) that has proven viability, reliability, flexibility, and ease of extending in some recent works (Fosalau et al., 2016). WSN is also suitable for MEWS established in harsh environments because sensor nodes use its internal battery. However, the main disadvantage of WSN is that it has low bandwidth and short range communication. Moreover, WSN exists limitations of processing capability and storage of individual sensor nodes. If WSN is used for a long-term MEWS of landslide, dissipation of energy in sensors, microcontroller units, and transceivers of sensor nodes is a critical issue. Thus optimization of the energy consumption for WSN is still needed better solutions.

Literature review shows that various solutions for reducing energy consumption and extending the WSN lifetime have been proposed i.e. data compression (Alsheikh et al., 2016), low energy architecture sensor nodes (Zet et al., 2016), routing protocols (Nguyen et al., 2015; Pantazis et al., 2013), layer optimization and sampling rate changing (Nguyen et al., 2015). In general, these provide better dynamic tradeoff solutions among performance, communicate range, and network's lifetime. Nevertheless, optimization of the energy consumption in sensor nodes of WSN is still critical. According to (Nguyen et al., 2015), a battery 6600mA only uses for 7.6 days for their sensor nodes in active mode, and this is clear not sufficient for long time MEWS.

This paper addresses the aforementioned critical issue by proposing a new flexible method for the configuration of MEWS for rainfall-induced landslides aiming to extend the life time of the MEWS system. The proposed configuration is an integration of the star topology and the tree topology. Accordingly, when a landslide is monitored and analyzed its instability by mean of Factor of Safety (FoS), the tree topology is used if FoS larger than 1, called normal condition. For this case, sensor nodes near the gateway switch to router mode. On contrast, in warning condition, the star topology will be automatically used, and in this case, sensor nodes far from the gateway in the star topology will consume much energy, but the network is reliable.

2. BACKGROUND OF WIRELESS SENSOR NETWORK AND ITS TOPOLOGY

2.1 Wireless Sensor Network

A WSN could be defined as a set of sensed devices (also called sensor nodes) that are spatially distributed in the rainfall-induced landslide being considered, in which sensors could sense parameters of the landslide (e.g. soil moisture in slope soil, tilt, and vibration), and these sensor nodes wirelessly communicate the obtained parameter values via wireless links. The data values are then transferred to a sink to connect to the internet or other networks through a gateway (Buratti et al., 2009).

WSN has been success fully applied for various real-world problems such as food and agriculture monitoring (Yu et al., 2013), flash-flood alerting (Castillo-Effer et al., 2004), civil structures monitoring (Chintalapudi et al., 2006), underground structure monitoring (Li and Liu, 2007). However, few researches on application of WSN for landslide study have been carried out i.e. landslide detection (Ramesh, 2014), landslide prediction (Sheth et al., 2005), and landslide early warning system (Intrieri et al., 2012). Therefore, research on WSN for landslide MEWS should be still carried out.

2.2 Topology of Wireless Sensor Network

Designation of an effective landslide MEWS requires determining an appropriate topology for WSN. This is a critical importance to ensure both the reliability and the energy conservation of WSN (Akyildiz and Stuntebeck, 2006). Literature review shows that various types of topology for WSN have been used i.e. underground topology and hybrid topology (Akyildiz and Stuntebeck, 2006), mesh network topology and peer-to-peer topology (Buratti et al., 2009), star topology (Srbinovska et al., 2015), and tree topology (Chintalapudi et al., 2006). Different topologies were proposed because obstructions in the environment of real-world problems may limit or prevent communication between some nodes. In this section, the star topology and the tree topology (Fig. 1) are shortly discussed.

For the star topology, the coordinator (sink node, Fig. 1a) acts as the network controller and the other devices are called “end-devices”. The end-devices do not communicate directly with each other but operate independently; they communicate directly with the coordinator. More importantly, they are not affected by other end-devices when these devices do not operate.

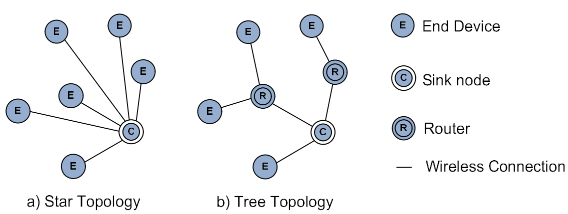

Fig. 1. Network topology: (a) Star topology and (b) Tree topology

In addition, a device may switch to the idle mode or the sleep mode in order to reduce the power consumption and extend the duration of the operation time of the sensor node. Because the end-devices communicate directly to the coordinator, the more distance between the end-device and the coordinator is, the more energy the transceiver spends. The star topology should be used for landslide monitoring when the landslide is active status.

Regarding the tree topology (Fig. 1b), the network consists of one coordinator, several routers, and end-devices. The coordinator sets up the network, selects the operating channel, give addresses for the routers and the end devices. The routers communicate directly with the coordinator. In the tree topology, the routers act as relays between the end-devices and the coordinator, therefore, the routers are always active that consume energy. However, the distance from the end-devices to the routers is shorter than those from the end-devices to the coordinator of the star topology (Fig. 1), therefore, the WSN system using the tree topology consumes less energy than that of the star topology. The tree topology should be used when the landslide is quite stable status.

3. EXPERIMENTS AND RESULT

3.1 Designation the Wireless Sensor Network System for Rainfall-induced Landslide

In this research, the WSN system was designed with 6 sensor nodes (Fig. 2) placed in positions on a slope surface established in the sensor lab of VNU University of Engineering and Technology (Vietnam). The sink node was placed near the slope at a safe distance. A rain gauge station, which connects directly to the sink node, provides monitoring data of rainfall, intensity, and duration. The sensor nodes near the sink node can switch between the two functions, the router and the end-device. Besides the battery power, the sensor nodes operating as the routers are also powered by solar panels. The sensor nodes that are far from sink node are set up as the end-devices.

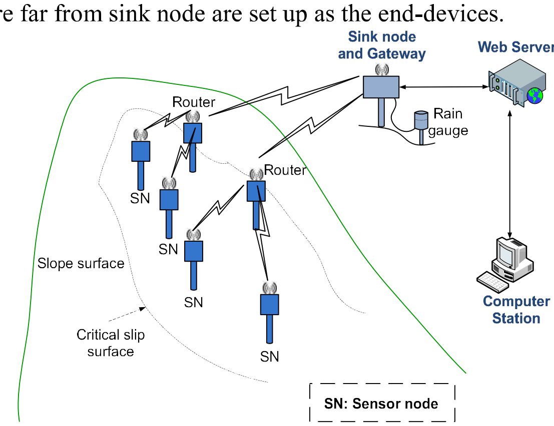

Fig. 2. The network of sensor nodes used in this research

It is noted that these end-devices can directly communicate with the coordinator (the star topology) or through the routers (the tree topology). Data is transferred to the sink node for further processing. A gateway connects the WSN to the internet to expand the ability of communication. A computer station uses the field survey and real-time data acquired from WSN for analyzing the status of the slope.

3.2 Designation of the Sensor Nodes for Rainfall-induced Landslide

Block diagram of a sensor node is shown in Fig. 3a, including sensors, Waspmot board, rechargeable battery, XBee-Pro ZigBee RF module. A real sensor node is shown in Fig. 3b. In this research, three types of sensors (soil moisture sensor, temperature sensor, and acceleration sensor) were used. The operation time of the

Waspmote board, which is powered by a battery, can be 1 to 5 years, depending on the mode of operation. In this study, a Waspmote PRO v1.2 designed with an ATmega1281 microcontroller (frequency 14MHz, SRAM 8KB, Flash 128KB) is employed for sensor nodes, and XBee module is used for wireless communication. We use a rechargeable battery (6600mAh and 3.7V) for the sensor nodes. For those acts as the routers, the extra solar panel is employed.

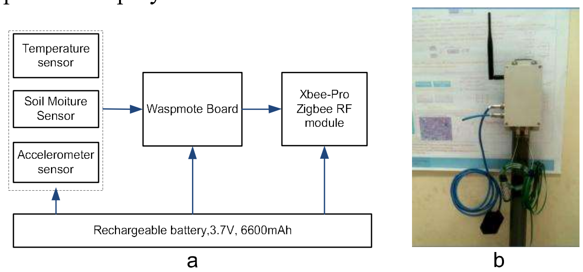

Fig. 3. (a) Block diagram of a sensor node; (b) a photo of a real sensor node

Regarding the ZigBee network**,** we select the ZigBee for landslide monitoring in this study due to low power consumption. This is an RF protocol, in which two lower layers, MAC (Media Access Control) and Physical layers, are defined by IEEE 802.15.4. ZigBee is targeted for using in WSN with low power, low bandwidth, and short communication range.

3.3 Working Principle of the WSN System

The sensor nodes sense the slope parameters and transfer the data to the sink node, then, the gateway uploads this data to the web database via the internet. The data is analyzed at the station using the GeoStudio software to assess the status of the slope, stable or unstable, in term of Factor of Safety (FoS) (Fig. 4).

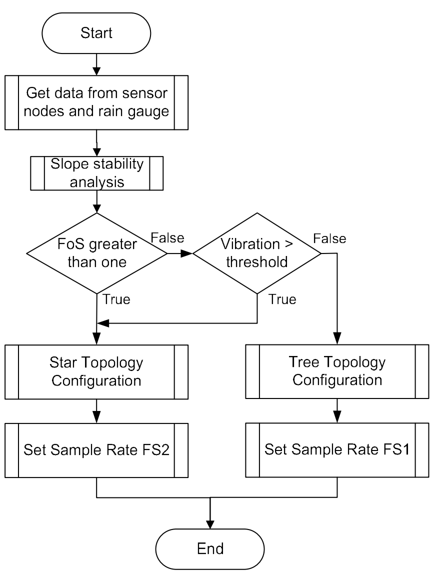

Fig. 4. Working principle of the proposed system

It is noted that based on the FoS values, the system could be switched between the tree and star topology. In this study, we divide the operation of the system into two scenarios: 1) normal mode; 2) warning mode. The first scenario is a safe condition when the weather is good, pore water pressure is low and the slope vibrates below a threshold. The second scenario is an unsafe condition in which the weather is bad, pore water pressure is high and the slope vibrates over a threshold.

In the normal mode, FoS is much greater than one, the network uses the tree topology. Whereas in the warning mode, the slope is low stability or vibrates over a threshold, the priority of the system is data collection; therefore, the high sample rate and transfer rate are used to monitor the slope's condition. If FoS increases, the slope comes back the safe state, the network switch from the star topology to the tree topology. Accordingly, the sensor nodes turn into the idle mode to save energy. The power for the sensors is turned off, and the Waspmote board and the RF module also switch to the idle mode.

3.4 Results and Discussion

The result of the estimation of the power consumption is shown in Table 1. It could be seen that the power a sensor node consumed in the active mode is 100.255mW. For the battery with the capacity of 6600mAh and voltage of 3.7V, the maximum power supply for a sensor node is 24420mWh. Therefore, the working time of the sensor node may extend roughly to 243.5 hours.

Table 1. The power consumed by a sensor node

Module	Power (mW)	
	Idle mode	*Active mode*
Waspmote	0.18	49.5
XBee-PRO ZigBee		10 mW (+10dBm)*
Accelerometer		1.155
Soil moisture sensor		6.6
Temperature sensor		33

*Note: * for international variant*

In fact, the efficiency of the battery is much smaller. For example, if the efficiency is 75%, the working time decreases to 182.6 hours. This working time is not enough for the long time monitoring. In order to extend the lifetime of the network, the sensor nodes should only be active in limited time and turned to the idle mode.

In the normal operation mode, the end-devices only active 3 seconds after staying 10 minutes in the idle mode. The power the sensor node uses is 0.656mAh. Therefore, the lifetime of the sensor node is 1163 days considering the efficiency is 75%. In warning operation mode, the sensor node active 3 seconds after staying 1 minute in the idle mode. The lifetime of the sensor node is 161 days considering the efficiency is 75%.

The above result is clearly better than in the previous works in (Nguyen et al., 2015) in term of the power consumption. In (Nguyen et al., 2015), the network is switched from the tree to the star topology when the rainfall reaches to the determined threshold. It happens even though the FoS is still high (i.e. FoS >>1). In our work, the WSN system is switched from the tree to the star topology only when FoS reaches to 1. Thus, more power can be saved.

One of the most critical issues of the WSN is the transmission reliability. In this research, the transmission reliability of the proposed WSN system is assessed using Packet Delivery Ratio (PDR) measure. This is the ratio between the number of messages that the sensor nodes transmitted and the number of messages the sink node received. The experimental scenario and result is shown in Fig. 5 and Tables 2. It could be seen that the total number of packets the sensor nodes sent is 730, whereas the total number of packets the sink node received is 730 for both the star topology and the tree topology, therefore, the PDR parameter is 100%.

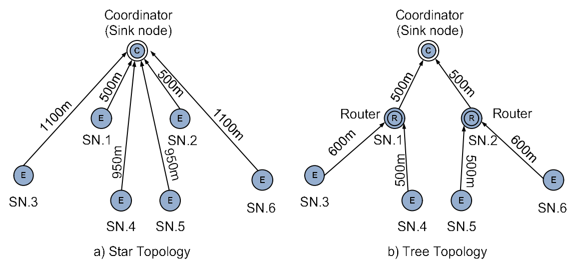

Fig. 5. Scenarios for outdoor experiment; (a) star topology; (b) tree topology

Table 2. PDR for the tree and star topologies.

Node	Total of transmitted packets	Total of received packets (Tree topology)	Total of received packets (Star topology)	Percent of received packets (Tree topology)	Percent of received packets (Star topology)
1	140	140	140	100%	100%
2	103	103	103	100%	100%
3	127	127	127	100%	100%
4	109	109	109	100%	100%
5	133	133	133	100%	100%
6	118	118	118	100%	100%

4. CONCLUDING REMARK

This research has proposed a new flexible system for the configuration of MEWS for rainfall-induced landslides. The proposed system is a combination of the star and the tree topologies to use in different scenarios of monitoring that is not only to save energy and but also to improve operational reliability of the MEWS system. The star topology is used when the movement rate of the landslide is high (FoS $\leq$ 1), whereas the tree topology is employed when the slope is stable (FoS > 1).

Experiment result showed that the performance of the MEWS with the proposed method WSN is better than those from the conventional systems using only the tree topology or the star topology. The result of this study is useful for designing wireless sensor networks for MEWS of rainfall-induced landslides.

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